Total number of printed pages–9

53 (FPT 403) TPEN

2014

TRANSFER PROCESS ENGINEERING

Paper : FPT 403

Full Marks : 100

Time : Three hours

The figures in the margin indicate full marks for the questions.

*Answer **any five** questions.*

1. *(a)* State Newton's law of viscosity. What is the S.I. unit of viscosity ? Explain the variation of viscosity with temperature for liquids and gases. 2+1+3=6

Contd.

(b) Prove that the parabolic velocity distribution of a liquid of density (ρ) flowing over a vertical flat plate of length (L) and width (W) is

$$v_z = \frac{\rho g \delta^2}{2\mu}\left[1-\left(\frac{x}{\delta}\right)^2\right]$$

where,

v_z = Velocity of fluid in the z-direction

δ = Thickness of the liquid film forming over the flat plate

x = Distance of a shell of the liquid

μ = Viscosity of liquid

And hence find the average velocity and mass flow rate of fluid over the plate. 8+3+3=14

2\. (a) Derive time-smoothed continuity equation. 3

(b) Explain time-smoothed velocity profile near a wall.

Show that the thickness of the viscous sub-layer (y) is $\frac{5v}{u^*}$, where

v = Kinematic viscosity and

u^* = Frictional velocity 4+5=9

(c) Derive the general form of time-smoothed Navier-Stoke equation of the turbulent flow in vector form as shown below :

$$\frac{\delta}{\delta t}(\rho \overline{V}) = -\nabla \overline{\rho} - [\nabla . \rho \overline{V} \overline{V}] - [\nabla . (\overline{\tau}^{v} + \overline{\tau}^{t})] + Pg$$

where, the symbols have their usual meanings. 8

3. (a) Define *three* modes of heat transfer 3

(b) State Fourier's law of heat conduction. How does thermal conductivity vary with temperature for the gases and liquids ? 2+2=4

(c) Consider a $3m$ high, $6m$ wide and $0{\cdot}3m$ thick brick wall whose thermal conductivity is $K = 0{\cdot}8 w/m^{o}C$. On a certain day, the temperatures of the inner and the outer surfaces of the wall are measured to be $14°C$ and $6°C$ respectively. Determine the rate of heat loss through the wall on that day. 3

(d) A hollow sphere, 10*cm* I.D. (Inner diameter) and 30*cm* O.D. (Outer diameter) of a material having thermal conductivity, $50W/mK$ is used as a container for a liquid chemical mixture. Its inner and outer surface temperatures are 300°*C* and 100°*C* respectively. Determine —

(i) The rate of flow through the sphere.

(ii) The temperature at a point, a quarter of the way between the inner and the outer surfaces. 10

4. (a) Consider a 1·2*m* high and 2*m* wide glass window whose thickness is 6*m* and thermal conductivity is $K = 0{\cdot}78 \quad w/m^o C$. Determine the steady rate of heat transfer through this glass window and the temperature of its inner surface for a day during which the room is maintained at 24°*C* while the temperature of the outdoors is –5°*C*. Take the convection heat transfer coefficients on the inner and the outer surfaces of the window to be $h_1 = 10\, w/m^3\, {}^oC$ and $h_2 = 25 w/m^{2\,o}C$. 7

(b) Show that the rate of heat flow through a composite hollow cylindrical pipe of length (L) consisting of two co-axial layers of thermal conductivities, K_1 and K_2 if hot milk is flowing inside this pipe is

$$Q = \frac{2\pi L\left(T_{\infty 1} - T_{\infty 2}\right)}{\frac{1}{h_1 r_1} + \frac{1}{h_2 r_3} + \frac{ln\left(r_2/r_1\right)}{K_1} + \frac{ln\left(r_3/r_2\right)}{K_2}}$$

where r_1 and r_2 are the inner and outer radii of inside cylinder and r_3 is the outer radius of outside cylinder.

h_1 and h_2 are the convection heat transfer coefficients at the inner and the outer surfaces of the pipe.

T_{α_1} and T_{α_2} are the milk temperature and the outside pipe air temperature respectively. 5

(c) Prove that the temperature distribution at any radius *(r)* in a solid cylindrical rod due to the passage of an electric current is

$$T = T_0 + \frac{\dot{q}}{4K} r_0^2 \left[1 - \left(\frac{r}{r_0}\right)^2\right]$$ 8

where,

$\dot{q} =$ Heat generation within the rod due to the passage of an electric current.

$T_0 =$ Surface temperature of the rod

$r_0 =$ Radius of rod

$K =$ Coefficient of thermal conductivity.

5. (a) Define Nusselt Number ? How will you explain the physical significance of the Nusselt number ? 2+3=5

(b) What do you mean by Reynold's number ? For a flow of fluid over a flat plate, prove that the Reynold's number is

$$Re = \frac{VL}{v}$$

where, L = Characteristics length

$V =$ Average flow velocity

$v =$ kinematic viscosity 2+5=7

(*c*) Consider a $0{\cdot}6m \times 0{\cdot}6m$ thin square plate in a room at $30^{o}C$. One side of the plate is maintained at a temperature of $90^{o}C$, while the other side is insulated. Determine the rate of heat transfer from the plate by natural convection if the plate is vertical. 8

Given data :

The properties of air at the film temperature (T_f) of $60^{o}C$ and $1\,atm$ are :

K= $0{\cdot}02808\ w/m^{o}C$

Prandtl Number, P_r = $0{\cdot}7202$

Kinematic viscosity, $\nu = 1{\cdot}896 \times 10^{-15}\, m^2/s$

$$\beta = \frac{1}{T_f}$$

Nusselt Number for natural convection,

$$Nu = \left\{ 0{\cdot}825 + \frac{0{\cdot}387 Ra_L^{1/6}}{\left[1 + \left(\frac{0{\cdot}492}{Pr}\right)^{9/16}\right]^{8/27}} \right\}^2$$

6. *(a)* State Fick's law of mass diffusion. 2

(b) A mixture of oxygen and nitrogen with their partial pressure in the ratio 0·21 and 0·79 is in a container at $25^o C$.

Calculate the molar concentration, mass density, mole fraction and mass fraction of each species for the total pressure of $1 bar$. Take, $R = 8{\cdot}314\, kJ/kmol.K$. 8

(c) Pressurised hydrogen gas is stored at $358K$ in a $4 \cdot 8m$ outer diameter spherical container made of nickel. The shell of the container is $6cm$ thick. The molar concentration of hydrogen in the nickel at the inner surface is determined to be $0 \cdot 087\, Kmol/m^3$. The concentration of hydrogen in the nickel at the outer surface is negligible. Determine the mass flow rate of hydrogen by diffusion through the nickel container if the binary diffusion coefficient for hydrogen in the nickel at the specified temperature is $1{\cdot}2 \times 10^{-12}\, m^2/s$. 5

(*d*) How does the mass diffusivity of a gas mixture changes with temperature and pressure ?

Prove that the diffusivities D_{AB} is equal to D_{BA} for an ideal gas where '*A*' and '*B*' are species. 2+3=5

7. Write short notes on ***any four*** of the follolwing : 5×4=20

(*a*) Importance of transport phenomena in food process engineering

(*b*) Thermal boundary layer on a flat plate

(*c*) Grashof Number

(*d*) Analogy between heat transfer and mass transfer

(*e*) Boundary conditions for mass transfer.

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